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SOME ASPECTS OF ELECTROLYSIS[1]

By Gellert Alleman[2]

Before the advent of the electric street railway, the life of iron pipes, especially those made of cast iron, seemed to be almost indeterminate. "The corroding canker and the gnawing tooth of time" apparently had little effect on those tubes, some of which had been buried in the earth for more than a hundred years. After the installation of the electric street railway, frequent breaks in pipes were experienced and the cause for these failures seemed to be shrouded in mystery. The manufacturer was suspected either of using inferior iron or employing a process which was not conducive for obtaining an efficient product; and those who laid the pipe were suspected of improper handling or installation. An examination of installed pipe sometimes revealed the fact that after the pipe had remained in the earth for a time, in apparent good condition, it suddenly began to deteriorate. Small or huge warts or concretionary deposits began to appear in spots, not regularly, on the outer surface and that which once was hard iron was later on apparently transformed to a substance easily cut by the finger nail or the blade of a knife. Frequent leaks, especially on high-pressure mains, developed. It was noticed that those pipes which were placed near electric street railway tracks seemed to be attacked by this mysterious disintegrating agent to a much greater extent than those pipes which were far removed from the electric street railway tracks, and, especially, that those pipes which were located in certain areas near the electric street railway power stations were particularly susceptible to this action. Later on it was found that an uninvited and unwelcomed guest was traveling on these sub-surface structures in order to find an easier path of return from the rail to the power station.

No possible objection would have been made to the presence of our traveler on the pipe provided it left the vehicle in the same condition as it found it; but, unfortunately, in leaving the pipe in its rush to reach the negative bus bar of the power station, the traveler abstracts a part of the iron of which the pipe is composed, carries it a short distance from the surface of the pipe and there leaves it. Iron which once leaves the pipe under these conditions is never returned.

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[1] Read at the Montreal Convention, June 23, 1920. Discussion is invited and should be sent to the Editor.

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All of us are, or should be, interested in the subject of electrolytic corrosion of sub-surface metallic structures. The company responsible for the escaping current not only loses the beneficial work of a valuable amount of energy, but also renders itself liable for the damage done by its stray current; the gas, water, telephone, and cable companies are particularly annoyed by the action of stray currents on their pipes and cables; the foundations of bridges, the reinforced concrete foundations of large buildings, and the iron shells of tunnels are endangered; and the public, which is dependent upon the integrity of the efficient and continuous operation of these utilities, is inconvenienced and exasperated whenever the service is interrupted or its efficiency lowered.

Some one ought to tell the truth about electrolysis. The electric railways are not anxious to do so because they are responsible for the damage caused and they see no reason why those affected should be informed or the public aroused. Their inquiry, "why awake a sleeping dog," is easily answered by the rejoinder that a dangerous thief stalks in the darkness underground and that the alarm should be given. Frequently the interests created by the joint ownership of gas, water and electric railway services, or by interlocking directorates, are responsible in some places for reticence.

Much has been written, but little told, about electrolysis. Unfortunately, and entirely too frequently, one sees in the daily press astonishing flare lines designed to excite, frighten or incense the public. The articles have been originated, in nearly every case, by so-called consulting electrical engineers whose services have been offered to, but declined by, the railways, and who seek to force their employment by the creation of public clamor. Such action is nothing less than blackmail. A number of suits entered on the recommendation of some of these self-styled consulting electrical engineers have been withdrawn after their employment or retention by the railway company. In these circumstances the water companies obtained no redress and no improvement in the existing conditions.

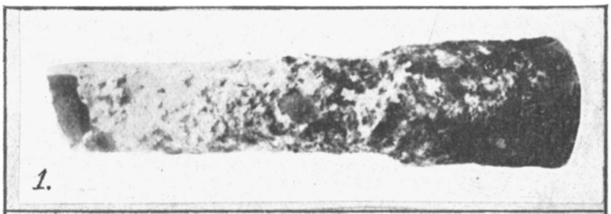
As the deteriorating action of an alternating current is almost negligible, provided the alternations are below 30 cycles per second, the author will confine his remarks to the effects produced by the direct current, especially on iron.

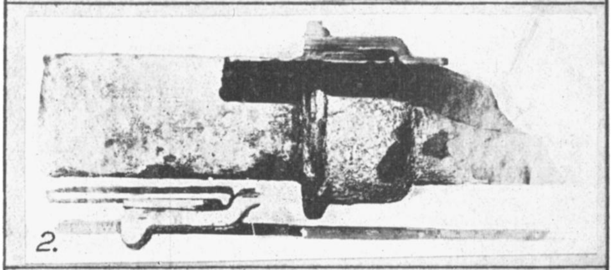
If an iron pipe and a steel rail are placed in *clean dry* sand and an electrical pressure (voltage) maintained between them, no damage takes place to either the pipe or the rail.

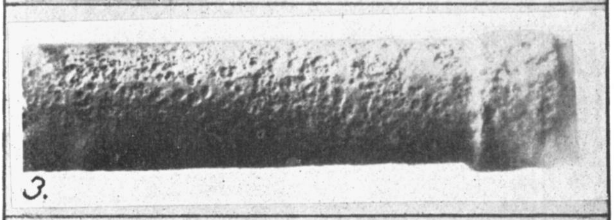
If an iron pipe and a steel rail are placed in *clean moist* sand, especially if the moisture holds an electrolyte like common salt, and a difference of electrical pressure is maintained between them that piece of iron which is positive will be dissolved by the current.

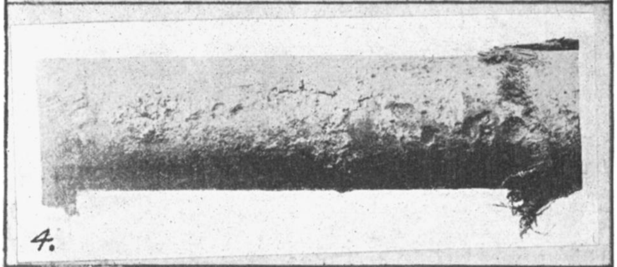
In the first instance no damage results because no current flows; in the latter case the iron which is positive dissolves because current is flowing, through the moist earth, from the positive iron to the negative iron. In order that a current may flow, it is necessary to have a difference of electrical pressure, moisture and an electrolyte, such as salt. Since practically all soils contain electrolytes and moisture, even if the latter is present to but a slight amount, it follows that when pipes are buried in most soils and a difference of electrical pressure exists between the soil and the pipe, or between the rail and the soil, a current will flow through the earth and enter the pipe provided the resistance of the rail or of the earth is greater than that of the pipe. It is a rule that the current, if free to travel on a number of non-metallic or metallic conductors, will follow the path of least resistance. No damage will result to the pipe as long as the current is on it, but when it leaves the pipe, through the earth, to return to the power station, it dissolves a certain amount of iron which is directly proportional to the amount of current leaving the pipe. This is equal to 0.00029 gram of iron per ampere per second (coulomb) or a little more than 20 pounds of iron if a current of one ampere flows continuously from the pipe for a period of one year. The same amount of current (one ampere flowing for one year) will dissolve or corrode about 74 pounds of lead.

It must be remembered that the current which leaves the pipe at one point may again return at another place, if the electrical conditions are favorable, and in the latter event a current of one ampere, flowing from the pipe for one year, may be responsible for the solution or corrosion of any multiple of 20 pounds of iron, or any multiple of 74 pounds of lead, the multiples depending on the number of times the current entered and left the pipe. Experience shows that this









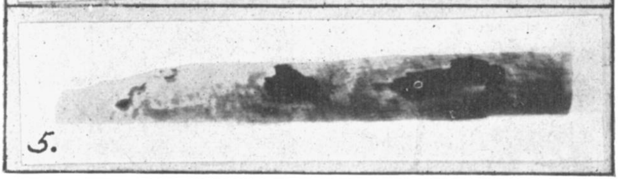


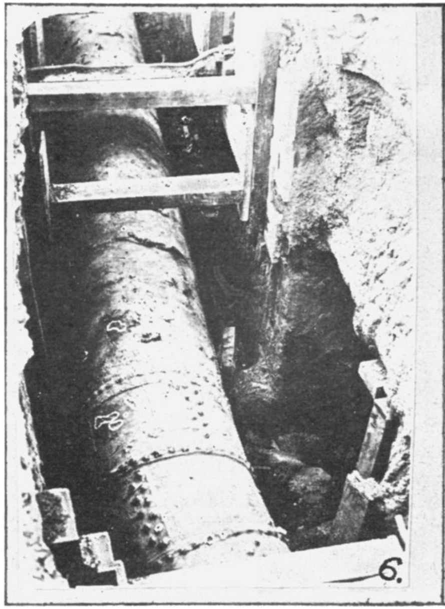
Fig. 1. Cast Iron Pipe After Service of 161 Years

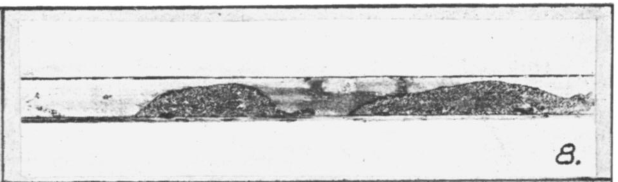
Fig. 2. Cast Iron Pipe in Service in Philadelphia 97 Years

Fig. 3. Characteristic Pittings Due to Electrolysis

Fig. 4. Pitting of Pipe Encased in Burlap Soaked with Asphalt, Showing that Outside Protective Coatings do Not Prevent Damage by Electrolysis

Fig. 5. Characteristic Action of Stray Current on Wrought Iron Pipe





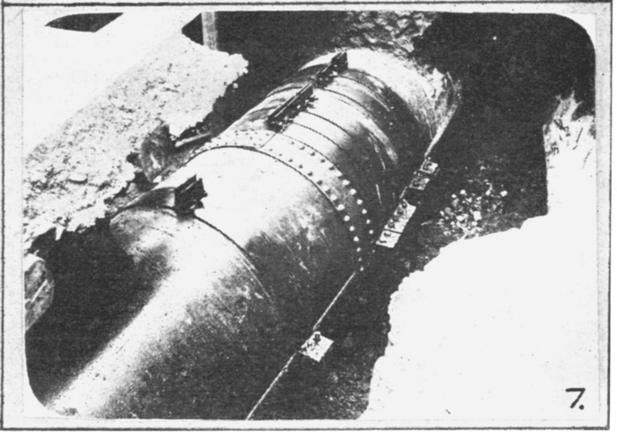


Fig. 6. Damage to Steel Main by Electrolysis, at St. Louis

Fig. 7. Method of Repairing Steel Main, Damaged by Electrolysis, at Wilmington, Del.

Iron bands are placed over lead plates and firmly fixed.

Fig. 8. Section of Cast Iron Water Main Showing How the Iron is Removed by the Current and Graphitic Carbon Remains

The darker sections indicate the carbon and the lighter sections the perfect cast iron.

multiple action certainly does take place, as the damage caused, in many cases, is actually greater than might be anticipated by the measurement of the current flowing from the pipe at any one point.

The current leaves the pipe at certain points, not uniformly distributed along an entire length of any pipe or of the whole system, because the moisture and the electrolytes in the soil at that point make better contact with the pipe and thus furnish an easier mode of exit for the current. This accounts for the "pitting" or the dissolving of one section of the pipe while another portion of that same pipe, quite near to the damaged part, is unaffected. It should be remembered that the solution of the iron first manifests itself on the outside, and proceeds, in the shape of a cone, extending towards the center, the larger area to the outer surface of the pipe, so that a section of such a damaged pipe presents somewhat the appearance of an open fan. Under the action of the current the iron first goes into solution and then reacts with the moisture present in the soil, forms a hydrate of iron which latter undergoes further change, and the final result is that there is found clinging to the outer surface of the pipe, and extending towards the negative pole, a hydrated oxide of iron. These electrolytic hydrated oxides of iron are different in physical properties and chemical composition from ordinary iron rust and an examination of the corroded specimens furnishes one of the methods by means of which electrolyzed pipe may be differentiated, with certainty, from pipe which has been damaged by ordinary corrosion.

While differences of electrical pressure between rail and pipe and between pipe and earth are not always indicative of current flow through the earth, these differences of electrical pressure, when one considers the character of most soils, furnish the ground for suspicion that the pipes may be subjected to damage.

It has frequently been stated that in order to cause damage to pipes the difference of electrical pressure between pipe and rail must be at least equal to the "decomposition voltage" of electrolytes occurring in the soil ($NaCl = 4.23$ volts). Such assertions are contrary to experience, and it has been clearly demonstrated that it is the solvent action produced by the current which is responsible for the damage. A slight difference of electrical pressure may be accompanied by a considerable flow of current or, on the contrary, a comparatively high difference of potential between rail and pipe may be accompanied by a much smaller flow of current.

In this connection it may be of interest to refer to a few of the results which the author obtained when attempting to determine the relative action of the current on pipes subjected to the action of various electrolytes and various electrical pressures. The electrolytes consisted of 0.05 per cent solutions of sodium chloride, potassium nitrate, and, in some cases, mixture of these two salts. The differences of electrical pressure ranged between 0.2 and 1.3 volts. The averages for 44 tests are given in Table 1.

TABLE 1

Relative action of electric currents of different voltages on metal in the presence of various electrolytes

	GRAMS IRON LOST PER COULOMB			GRAMS IRON LOST PER AMPERE HOUR			POUNDS IRON LOST PER AMPERE YEAR		
	Theory	Actual		Theory	Actual		Theory	Actual	
		In water containing electrolytes	In soil containing electrolytes		In water containing electrolytes	In soil containing electrolytes		In water containing electrolytes	In soil containing electrolytes
Cast iron anodes..	0.0002902	0.0003173	0.0003130	1.0447	1.1423	1.1268	20.17	22.06	21.77
Steel anodes..	0.0002902	0.0003434	0.0003608	1.0447	1.2362	1.2989	20.17	23.87	25.08
Wrought iron anodes..	0.0002902	0.0003404	0.0003390	1.0447	1.2254	1.2204	20.17	23.66	23.56
Piano wire anodes..	0.0002902	0.0003708		1.0447	1.3349		20.17	25.77	

44 tests: 19 cast iron; 11 steel; 12 wrought iron; 2 piano wire.

It is clear, from the results in Table 1 that the low differences of potential, during the flow of current, have as much influence as much higher differences of potential if accompanied by the same flow of current. It, therefore, appears that the recent recommendation of the representative of one of the United States Government bureaus that a difference of potential of ½ volt between rail and pipe be permitted, was not calculated to afford protection to the pipes and that the objection made to this recommendation by the electrolysis committee of the American Gas Association was well founded.

Nowadays one hears much about the desirability of the coöperation of all concerned in an attempt to mitigate or control this serious menace. We all heartily believe in coöperation as that word is usually understood, but of late, Americans are only too familiar with investigating committees and commissions. There are two general types of these bodies: The one is well organized, composed of men of ability and decision, who, without unnecessary delay, secure the data required, make the proper deductions and apply, with dispatch, an efficient remedy. This type of commission is responsible for the many important advances made in this field. But there is another type. Unfortunately, many of these latter are organizations masquerading under the cloak of coöperation but which are, in reality, an aggregation of skilfully picked, highly trained, technical, professional or business men who have been selected to advise these committees and whose dominating object is to balk or delay any decisive action which might be disadvantageous to the railways until a new general manager appears, or until the property, with this particular liability, passes into the hands of new owners. The technical members of this type of committee are usually honest and efficient but are merely tools in the hands of the initiated. Moreover, it too frequently happens that the men who control the appointment of these committees are advocates of some particular theory, with the result that judicial recommendations are secondary to those of policy or of expediency.

The methods of procedure of some of these joint electrolysis committees appointed for the avowed purpose of coöperating with all concerned suggest that a thievery has taken place, the culprit apprehended and that he kindly and considerately consents to confer with the rightful owner of the goods with a view of discussing who shall retain the property or who shall be responsible for the damage caused by entry.

Sometimes efficient methods of protection are proposed, but the proposals are objected to and the installation prevented, solely on the ground that the carrying out of these suggestions might result in damage to some other sub-surface structure.

Sometimes hesitation and delays result in an honest effort to decide upon the best method to pursue. Frequently, there is some justification for this fear and hesitation. Last year, a large steel water main in St. Louis was connected to the track, for electric drainage purposes, by means of a copper cable and the current on the main immediately increased from 17 amperes to 480 amperes. Had this latter current been allowed to continue to flow through the earth to the pipe for a period of one year, it would have been responsible for dissolving, from some other pipes, 9600 pounds of iron or about 4.8 tons.

In demanding our own protection we should see that methods are employed which, if they may not benefit, certainly do not injure our neighbor. But our neighbor must not place the burden of his protection on us. Coöperation is not one sided; it involves mutual obligation and responsibility.

Iron pipes when electrically negative are not corroded by the current, but the assumption that all metals when electrically negative are immune under these conditions is incorrect. For instance, lead pipes are corroded when electrically positive and, under certain conditions, are also corroded when they are electrically negative. In the first instance the lead is dissolved by the current; and when electrically negative they may be attacked by products resulting from the action of the current. *This action accounts for the fact that the telephone interests prefer to have their lead sheaths electrically neutral. Lead water pipes should also be electrically neutral.*

Upon first consideration, it seems strange that an electrically insulating substance such as "pipe dip" should not effectively protect a pipe against electrolytic corrosion. On close examination it appears that the hydrocarbon substances constituting the "dip" are oxidized by the oxygen set free by the current and the material at that particular point is converted into a porous substance and no longer is able to insulate the pipe electrically. This action is not brought about by a "break-down" voltage but by the slow or rapid absorption of oxygen and the oxidation of the hydrocarbons constituting the dip. This action is especially rapid when the dips are made of coal tar products which contain electrolytes, unless the "tar acids" have first been completely removed.

One wonders why the stray currents from the street car tracks have been allowed to do so much damage to the iron and lead pipes of the water and gas companies and so little damage to the lead sheaths containing the telephone cables. The answer is evident. The telephone interests and the railways have been represented by able men who have accurate knowledge of matters pertaining to stray currents; the water and gas companies have too frequently been victimized by former readers of gas meters or street car motormen who have suddenly blossomed forth as consulting electrical engineers and electrolysis experts and who have been permitted to install costly and elaborate mitigating systems many of which have been about as successful as the supposed capture of a bird by the addition of salt to its tail. The electrical interests would no more think of employing these self-styled electrolysis experts for technical advisers on electrical matters than a water board would consider the advice of the Water Witch or the Divining Rod in preference to the opinions of eminent hydraulic engineers.

Frequently we have been contented to accept the well intended reports and recommendations of committees, forgetting that it requires an executive with authority and energy to carry out these ideas. It must be remembered that the giving of a promissory note may delay, but never forestall, the payment of an obligation. Specifications alone, without provisions for their enforcement, "become as sounding brass or a tinkling cymbal," a law, non-compliance with which, exacts no penalty.

It should be insisted that the water department's specifications be carried out; and inspectors or advisers appointed and controlled by the departments, not by the railways, should see that the agreements made are fulfilled. It is far from the author's intention to suggest that any unnecessary additional burdens be placed on the shoulders of the electric railways, which are already suffering from paresis at one extremity, gout at the other, and Bright's disease in the middle. But it must be remembered that this is their Wild Indian, not the water department's, to control. Let them do so, if they will; make them, if they won't.